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Pipeline Leak Detection based on Fiber Optic Early-Warning System

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Abstract

This paper introduces an optical fiber early-warning system based on Mach-Zehnder in order to monitor the normal operation of pipelines. Three single-mode fiber in the cable which is buried along the pipeline probe vibration signal on the ground, in which the two was not in the same casing as a sensing fiber, the formation of intervention arm, the other one as the transmission fiber, the return of the interference signal. Laser driver launched a constant wavelength of the laser to ensure the consistency, the PIN received by photoelectric conversion of light into electrical signals, and then filtering and amplify to improve the signal noise ratio. After analog to digital conversion, Judging by the energy, system located the source of danger by relevant location algorithm, and ultimately implement the function of early-warning. Experiments show that in the case of 1 km long fiber optic cable, 4MHz sampling rate, Stolen by mining the damage simulation, system can be completed within 5 seconds of signal acquisition and processing to alarm and positioning. after 100 times of experiments, the system did not 1 omitted, and were able to make accurate target positioning within 25 meters, implement the function of early warning of pipeline safety.

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Keywords: fiber early-warning, pipeline safety, fiber sensor

1. Preface

Oil and Gas Pipeline as the main mode of transport is safe, economic, quality, etc, which have been widely used. However, pipeline cross through a variety of complex areas inevitably. Therefore, the buried pipeline will not only have been suffered by mudslides, landslides and other geological disasters, and sometimes subjected to mechanical construction, the human damage affected the operation of the pipeline directly, or even caused serious environmental pollution.

Optical fiber sensors is an emerging sensing technology, as opposed to the traditional negative pressure, acoustic, optical fiber sensor has the advantage of early-warning, can be real-time monitoring dangerous operation on the ground and pipeline leaks, when there is an emergency, system can alarm and locate the threatened position in order to avoid substantial economic losses.

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This paper introduces an optical fiber early-warning system based on Mach-Zehnder, which using the same trench with the pipe laying fiber optic cable in three single-mode optical fiber to detect the vibration signal on the ground, through a variety of signal processing methods to implement the function of early-warning, and locate the position accurately, to achieve early warning of pipeline safety, minimize the possibility of the destruction of the pipeline.

2. System Introduction

System is based on Mach-Zehnder optical fiber sensor to achieve the function of early warning, alarm by the interference of vibration signals. system positioning by the different time when the signal transmit through the different fibers, thus completing the system function.

2.1. System structure

system laid two cable boxes between the end of the two sides of a buried fiber optic cable to receive the interference signal. the source launch fixed-wavelength laser into the cable box. the optical detection system acquisit the vibration signal on the ground, when there is an emergency, vibration interference signal through the first side of the cable box to the photoelectric detection system to photoelectric conversion and pretreatment, AD converter into the computer after the software filter, threshold, the results will be displayed. System diagram shown in Figure 1:

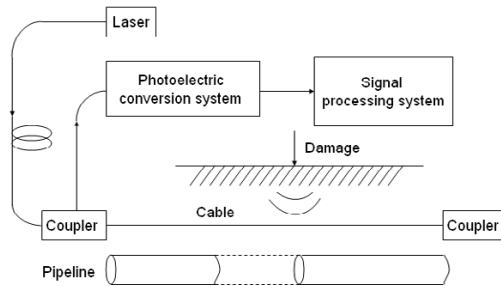


Figure 1 System Diagram

2.2. Optical structure

Optical fiber pipeline leakage and monitoring system using fiber optic cable laid with the groove 3 in the single-mode optical fiber constitute the optical fiber sensor, in which two single-mode fiber as the sensing fiber, the other one was used for signal transmission. The optical structure shown in Figure 2:

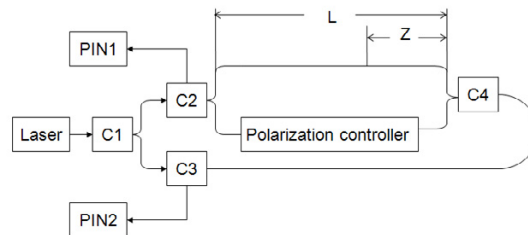


Figure 2 Optical structure

LD driver circuit provide a stable power output, laser light emitted by a 1:1 coupler C1 into two beams at the light, and then by coupler C2 is further divided into two beams by a 1:1 light, respectively to the two sensing optical fiber, the two sensing optical fiber cable are arranged in different positions, when external force on the sensor cable,

the resulting stress and strain is different, thus the sensing fiber in the 2 beam propagation phase change produced by coherent light is not exactly the same. Detection through real-time changes in interference light signal, the distributed optical fiber sensor can detect the micro-vibration generated along the signal, which occurred along the pipeline can be real-time monitoring.

2.3. Hardware Design

The hardware design of optical early warning system consist of the laser driver circuit and PIN receiving conditioning circuit, whose main function is the constant laser power emitted by the laser fiber optic cable laid along the pipeline transmission, while the optical signal through fiber optic cable in the PIN management receiver back into the system, after a hardware pre-processing circuit, put the analog signal into the data acquisition module for AD conversion, and data processing module converts the digital signal processing software, and finally to achieve the alarm location, hardware system block diagram shown in Figure 3:

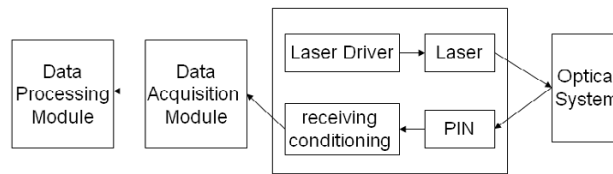


Figure 3 Hardware Structure

The entire hardware system consists of laser driver module, PIN receiving conditioning module, data acquisition module.

The function of laser driver module is to monitor the laser's operating current and operating temperature to ensure the normal operation of the laser. Including constant current source module, automatic power control module, slow start module, temperature control module and overcurrent module.

The function of PIN receiving conditioning module is PIN photoelectric through the light signals into analog electrical signals, then filtered noise removal, after the placement of a large increase of signal noise ratio, while the received signal PIN tube monitor, once the abnormal need for instant alarm to improve system reliability. PIN tube receiver module includes: pre-amplification, filtering module, adjustable gain amplifier module, system status monitoring module.

The function of data acquisition module is the signal after pre-analog conversion, as well as computer data interface signal processing systems, enables a computer to direct the collected signal processing.

2.4. Software Design

System software consists of data acquisition module and data processing module.

Data acquisition module using the data acquisition card PCI1714, by configuring the appropriate DMA transfer mode, set the sampling rate, set the data size to complete the process of writing data acquisition module to complete the analog signals into digital signals and stored to the corresponding follow-up within the array signal processing. Specific flow chart shown in Figure 4:

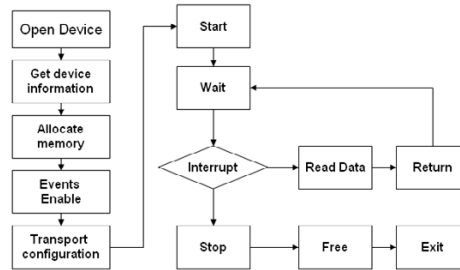


Figure 4 Data Acquisition Flow Chart

The main function of the data processing module is to collect the data points to the frame processing, when there is an emergency, PIN tube collected signal $S_1(t)$ and $S_2(t)$ exists only on the arrival time is different, if only different time then:

$$S(t) = S_1(t) \quad (1)$$

$$S(t + \Delta T) = S_2(t) \quad (2)$$

Available in accordance with the correlation:

$$F_{S_1 S_2} = \int S(t + \tau) S(t + \Delta T) dt \quad (3)$$

Threshold is the system settings can be adjusted by setting the threshold sensitivity of the system, when the damage occurs, there is only a time delay between two waveform, a strong peak obtained by the above formula, if more than set threshold that is determined to sabotage the event, and then calculate the location of damage events, and be displayed.

Local surface damage signal occurs when the threat to the pipeline, the location of the optical signal by the vibration of the Mach-Zehnder interferometers have optical path difference of two arms, resulting coupler C2, C4 at the interference signal changes. Different positions due to vibration, the time to reach both ends of the coupler is different, so by the time difference can be calculated at the damage occurred.

It can be seen from Figure 2, the forward transmission of light through the transmission fiber coupler C3 arrival time is:

$$t_1 = \frac{L + Z}{v} \quad (4)$$

Reverse transmission of light through the transmission fiber coupler C2 arrival time is:

$$t_2 = \frac{L - Z}{v} \quad (5)$$

Forward and reverse transmission of light reaches the photoelectric conversion circuit of the time difference is:

$$\Delta t = t_1 - t_2 = \frac{2Z}{v} \quad (6)$$

Where v is the propagation of light in the fiber speed, Δt is the time difference between forward and reverse transmission optical signal reaches the photoelectric conversion circuit, x is the threat generated at the first side from the location of fiber optic sensors, which can be calculated by cross-correlation function:

$$x = L - Z = \frac{2L - v\Delta t}{2} \quad (7)$$

3. Field test and results analysis

3.1. Test conditions

Test environment is a test tube, the total length of the cable is about 500m, optical cables is buried, fiber optic cable in the use of the 3 core principles constitute the Mach-Zehnder interferometer light warning system, while the

location was marked on the cable to verify fiber positioning accuracy. Optical fiber light source of early warning systems using semiconductor laser LD, wavelength is 1550nm.

3.2. Experimental data

Test simulations using shovels in the ground to simulated the stolen, when digging to a certain depth system began to alarm and positioning, the waveform shown in Figure 5:

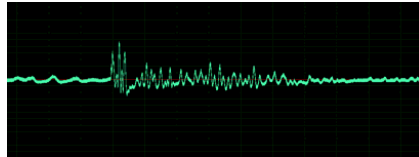


Figure 5 Experimental destruction of the waveform

Data acquisition and position on the situation of different speed of light, 2 groups positioning data were recorded:

Table 1 Positioning based on speed 1

Expected	Actual 1	Actual 2	Actual 3	Actual 4	Actual 5	Actual 6	Actual 7
20	17.84	17.88	17.84	17.50	17.88	17.88	17.50
84	71.43	75.25	75.25	71.43	98.21	71.43	98.21
144	151.79	156.3	160	156.3	156.3	151.79	151.79
203	232.14	239.14	228.3	230.17	239.14	232.14	228.3
267	312.5	317.5	310	312.5	312.5	312.5	317.5
322	366.07	361.5	366.07	362.74	361.5	366.07	362.74
380	419.64	420.5	420.5	420.5	418.6	420.5	419.64

Table 2 Positioning based on speed 2

Expected	Actual 1	Actual 2	Actual 3	Actual 4	Actual 5	Actual 6	Actual 7
20	19.512	17.866	17.866	18.5	17.866	18.5	19.512
84	71.43	98.213	75.25	71.43	98.213	75.25	75.25
144	151.79	151.39	151.79	151.79	151.79	151.39	151.79
203	205	205.36	205.36	232.1	205.36	205	205.36
267	285.71	285	285.71	285.71	259	285.71	259
322	312.5	339.29	339.29	339.29	339.29	312.5	339.29
380	392.86	396.86	392.86	419.64	419.64	396.86	419.64

Conducted a total of 14 group test, took seven different experimental points excavation experiments, can be drawn from the table:

Table 3 Speed 1

Expected	Average	Location error (absolute value)
20	17.74333	2.25667
84	78.65444	5.34556
144	155.93	11.93
203	233.1689	30.1689
267	313.6111	46.6111
322	364.3144	42.3144
380	420.2922	40.2922

Table 4 Speed 2

Expected	Average	Location error (absolute value)
20	18.44311	1.55689
84	79.07956	4.92044
144	151.6567	7.6567
203	208.2511	5.2511
267	273.76	6.76
322	333.3367	11.3367
380	403.5644	23.5644

Calibration of both the speed of light, seen from the case 1, the positioning error increases with increasing distance increases the error in the 200 meters near the positioning error of up to 30 meters, 267 meters maximum error reached 46 meters, has been 4MHz sampling rate is greater than the system error that should be achieved; and case 2, the positioning accuracy of the largest in the 380 meters at 23.5 meters which is in the required range.

3.3. Analysis

We can see from the field test data, early-warning system based on Mach-Zehnder can be about 25 meters on the positioning accuracy in the 500m of cable. To consider future improvements increase the sampling rate, can be more precise location accuracy, consider joining the advanced signal processing algorithms to identify the classification of the signal to avoid false positives on the non-threatening events, reducing false alarm rate and improve overall system performance, achieve real-time monitoring of pipeline safety.

4. Conclusion

This paper presents an optical fiber early warning system based on Mach-Zehnder, which constitute the optical fiber by using 3 Mach-Zehnder interferometer, and to calibrate the speed of light. The test proved that the system of micro-vibration testing ground signal responsive, high positioning accuracy and safe operation of the pipeline can be real-time monitoring.

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